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2018-02

Kukkonen , M O , Muhammad , M J , Käyhkö , N & Luoto , M 2018 , ' Urban expansion in Zanzibar City, Tanzania : Analyzing quantity, spatial patterns and effects of alternative planning approaches ' , Land Use Policy , vol. 71 , pp. 554-565 . https://doi.org/10.1016/j.landusepol.2017.11.007

http://hdl.handle.net/10138/323846
https://doi.org/10.1016/j.landusepol.2017.11.007

# Urban expansion in Zanzibar City, Tanzania: Analyzing quantity, spatial patterns and effects of alternative planning approaches

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Land Use Policy, 2018 - Elsevier

**Abstract**

Rapid urbanization and urban area expansion of sub-Saharan Africa are megatrends of the 21st century. Addressing environmental and social problems related to these megatrends requires faster and more efficient urban planning that is based on measured information of the expansion patterns. Urban growth prediction models (UGPMs) provide tools for generating such information by predicting future urban expansion patterns and allowing testing of alternative planning scenarios. We created an UGPM for Zanzibar City in Tanzania by measuring urban expansion in 2004–2009 and 2009–2013, linking the expansion to explanatory variables with a generalized additive model, measuring the accuracy of the created model, and projecting urban growth until 2030 with the business-as-usual and various alternative planning scenarios. Based on the results, the urban area of Zanzibar City expanded by 40% from 2004 to 2013. Spatial patterns of expansion were largely driven by the already existing building pattern and land-use constraints. The created model predicted future urban expansion moderately well and had an area under the curve value of 0.855 and a true skill statistic result of 0.568. Based on the business-as-usual scenario, the city will expand 89% from 2013 until 2030 and will continue to sprawl to new regions at the outskirts of the current built-up area. Establishing new urban centers had the highest impact on directing urban expansion from the tested alternative planning scenarios. However, the impact of all scenarios was low and therefore also other planning solutions such as vertical development, urban growth boundaries, and gradual improvement of the informal areas should be considered in Zanzibar.

**Keywords:** Urban expansion, Urban growth, Urban Growth Prediction Models, Urban planning, Spatial modeling, Generalized additive model, GAM, Africa, Sub-Saharan Africa, Zanzibar, Stone Town

## 1. Introduction

Sub-Saharan Africa is facing both the fastest population growth and urbanization rates in the World (UN, 2004, 2010, 2014). It is estimated that the continent will more than double its current population of 1.1 billion to 2.4 billion by 2050 (UN, 2004, 2014). At the same time, the proportion of African population living in cities is expected to grow from 39.6% to 61.6% (UN, 2010). The urban population growth in Africa has a direct connection with expansion of urban area (Angel, 2011; Seto et. al., 2011; Linard et. al., 2013). It is estimated that urban land cover will increase five to twelve-fold in the region between 2000 and 2050 (Angel, 2011). Simultaneously, many African cities are approaching the second phase of urban growth, where majority of expansion will happen in suburbs outside the city's core (Chin, 2002; Linard et. al., 2013). It can be well said that urbanization and urban sprawl in Africa are megatrends of 21st century.

Urbanization in Sub-Saharan Africa is characterized by increasing proportion of poor people living in cities and also urban expansion happens mainly to inhabit the poorer segments of the society (Dye, 2008). Already, over 70% of urban Africans are living in slums and the newcomers are largely dependent on unplanned, unmonitored and irregularly placed housing (Cohen, 2006; Guneralp & Seto, 2008). This puts infeasible burden on the existing infrastructure, civil engineering and planning, which reflects back to the already marginalized and poor citizens as insufficient sanitation, power outage, overladen transportation and increased travel times (Keiner, Koll-Schretzenmayr & Schmid, 2005; Guneralp & Seto, 2008). Simultaneously, urban expansion has serious impacts on the quality of environment and ecosystem services (Lambin et. al. 2001; Seto et. al. 2011). It drives the loss of croplands, wetlands and forests, fragments natural habitats and affects local climate, hydrological cycle as well as surface water discharge (Eigenbord, et,. al. 2008; McDonalnd et. al., 2011; Seto et. al., 2011; Kukkonen & Käyhkö, 2014).

Addressing these accumulating environmental and social problems requires faster and more efficient planning of African cities (Couclelis, 2005; Vermeiren et. al., 2012). Traditional preventing planning with strict restrictions and zoning laws are seen sluggish against the extremely rapid sprawl of informal settlements (Kamete, 2011; Odendaal, 2012; Ngau, 2013; UN-Habitat, 2014). There is a need for adapting and predictive planning tools, which allow upgrading informal neighborhoods as well as estimating where developments are most likely to happen in the future (Couclelis, 2005; Vermeiren et. al., 2012). Also the resources for implementing any planning policies are limited, thus they should be targeted to the most effective activities. Unfortunately, the information required to estimate this effectiveness is often lacking in Sub-Saharan Africa (UN-Habitat, 2014).

Urban growth prediction models (UGPMs) offer promising tools for evidence-driven-decision-making in urban planning. UGPMs provide spatial predictions of cities future expansion based on retrospective data

(Doan & Oduro, 2012; Vermeiren, et. al. 2012; Arsanjani, et. al. 2013; Linard et. al., 2013). Besides creating predictions, UGPMs can be utilized to analyze the spatial patterns of urban expansion, test alternative planning scenarios, pinpoint unwanted environmental effects and make negative developments more tangible for decision makers (Couclelis, 2005; Vermeiren et. al., 2012). The modern UGPMs rely on the idea that cities expand according to spatial patterns determined by biophysical, social and economic factors as well as spatial policies and interactions (Poelmans & Van Rompaey, 2010).

Urban growth is complex and non-linear process, but century of research has shown that cities seem to grow according to certain principles (Cheng, 2003; Batty, 2008). Already the early sociological urban models, such as the *Von Thünen's* (1826) *model* and Burgess' (1925) *Concentric Zone Model* acknowledged that urban areas expand outwards from their Central Business Districts (CBD), while Hoyt's (1939) *Sector Model* and Harris and Ullmans' (1945) *Multiple Nuclei Model* developed these ideas further by theorizing that urban expansion happens along existing transportation networks, in a suitable topography, in a vicinity of similar land uses and outwards from multiple market centers. In urban economics, expansion has often been explained with *Monocentric City Model*, where land rent is function of distance from CBD, commuting cost, income and utility level. The urban area is then expected to expand until urban and agricultural land rents are equal (Deng et. al., 2008). Although many of these assumptions have been then proven empirically correct, both the sociological as well as the economic models fail to grasp the spatial and temporal complexity inevitably linked to growth of urban systems as well as the role of local actions (Batty, 1995; Deng et. al., 2008; Liu, 2009). Urban growth is spatially complex process where the reciprocal effect of various biophysical and socio-economic factors as well as spatial policies and dependencies impact growth patterns in a dynamic and non-linear manner. The temporal complexity is on the other hand evident in the difficulty of predicting urban growth in time, as it is closely related to economic and policy developments that are often non-predictable and fundamentally non-linear (Cheng, 2003). Even though of these apparent complexities, recent theories, such as *Self-organizing systems*, argue that there are still detectable patterns in urban expansion (Batty, 1995). In self-organizing systems it is assumed that largely irrelevant and highly complex local interactions eventually lead to recognizable urban patterns at higher levels, as urban systems have the ability to reorganize their spatial structure with endogenous force (Batty, 1995; Cheng, 2003; Triantakonstantis & Mountrakis, 2012).

Also the development of non-linear modeling methods together with GIS and accumulated remote sensing data has been able to shed light on these complexities (Liu, 2009). Meta-analysis of urban growth studies by Seto et. al. (2011) concluded that annual GDP growth, urban population growth and coastal location drove the quantity of urban expansion globally, though urban population growth was the most determinant factor in Africa. In the more detailed regional modeling of African cities, proportion of urban areas within 1 km neighborhood and travel-time distance to CBD were the most influential variables predicting urban growth patterns (Linard et. al, 2013). Other individual case studies have shown that high population density as well as vicinity of main roads and individual buildings attract more urban development, while presence of wetlands, conservation areas, land-use constraints, zoning restrictions and steep topography reduce the probability of expansion (Mundia & Murayama, 2010; Poelmans & Van Rompaey 2010; Eyoh, et. al. 2012; Vermeiren, et. al. 2012; Arsanjani, et. al. 2013).

Even though various factors have been shown generally to impact urban expansion patterns, the local reciprocal interaction of the biophysical, social, economic and policy factors create an outcome that is unique for each urban system (Lambin et. al., 2001; Cheng, 2003). Thus, UGPMs need to acknowledge and adjust to local circumstances. Also the spatial variables developed to reflect these factors are often crude simplifications of the reality (Poelmans & Van Rompaey 2010). Therefore, also the UGPMs are eventually simplifications of the complex urban growth processes, but their use has been justified by their relatively high prediction accuracies (Triantakonstantis & Mountrakis, 2012; Linard et. al., 2013).

Sub-Saharan Africa is facing the fastest spread of urban areas in the World, but urban expansion studies from the continent are limited and tend to focus on the mega-cities of the region (Barredo et. al., 2004; Taubenböck et. al., 2011; Doan & Oduro, 2012; Vermeiren et. al., 2012; Linard et. al., 2013). We directed our view to one of the region's secondary cities, Zanzibar City, which is facing extreme population growth, urban expansion and various related challenges, such as lack of planned housing and public infrastructure, congested traffic and encroachment of forests and agricultural land, but which is at the same lacking detailed knowledge about the quantity and spatial patterns of the expansion (RGZ, 2012, 2014; Kukkonen & Käyhkö, 2014). Therefore, we measured the urban expansion of Zanzibar City between 2004, 2009 and 2013 from remote sensing images. The 2004–2009 expansion data, along with environmental variables, were used to prepare UGPM for the city region and to predict business-as-usual urban expansion between 2013 and 2030. Alternative urban expansion scenarios were developed based on different spatial plans and it was tested how these plans direct urban expansion by comparing the scenarios to business-as-usual pattern. The results are discussed in the light of current and future patterns of urban growth in Zanzibar City, effectiveness of different planning approaches and how they should be acknowledged in currently prepared national land use plan, implications of the study to the general urban expansion theories as well as usefulness of UGPMs in context of rapidly growing African cities.

## 2. Materials and methods

### *2.1 Study area*

Zanzibar is a semi-autonomous part of Tanzania, with two main islands Unguja and Pemba. The capital Zanzibar City is located at the west coast of Unguja in the administration region of Mjini Magharibi (Figure 1). The capital region, as the entire Island, is generally flat with maximum altitude of 120 m.a.s.l. in Masingini forest area. The study area is mainly dominated by fertile sandy soils, while shallow unfertile coralline soils cover the south and southeastern parts (Hettige 1990).

The population of Zanzibar has grown rapidly in the recent decades (Thomas, 1968; NBS, 2004, 2013). Majority of this has been natural population growth, but growing tourism industry and economy has also attracted significant amount of migrants from mainland Tanzania and other parts of the East Africa. At the same time, there has been population movement from Pemba Island to Unguja Island as well as rural-urban migration within Unguja Island (RGZ, 2012; NBS, 2013). The population of Mjini Magharibi has increased over five-fold since 1970s due to these reasons (Thomas 1968; NBS 2004, 2013) (Figure 2). With the current annual population growth rate of 4.2% the region is reaching population of one million by 2025 (NBS 2013).

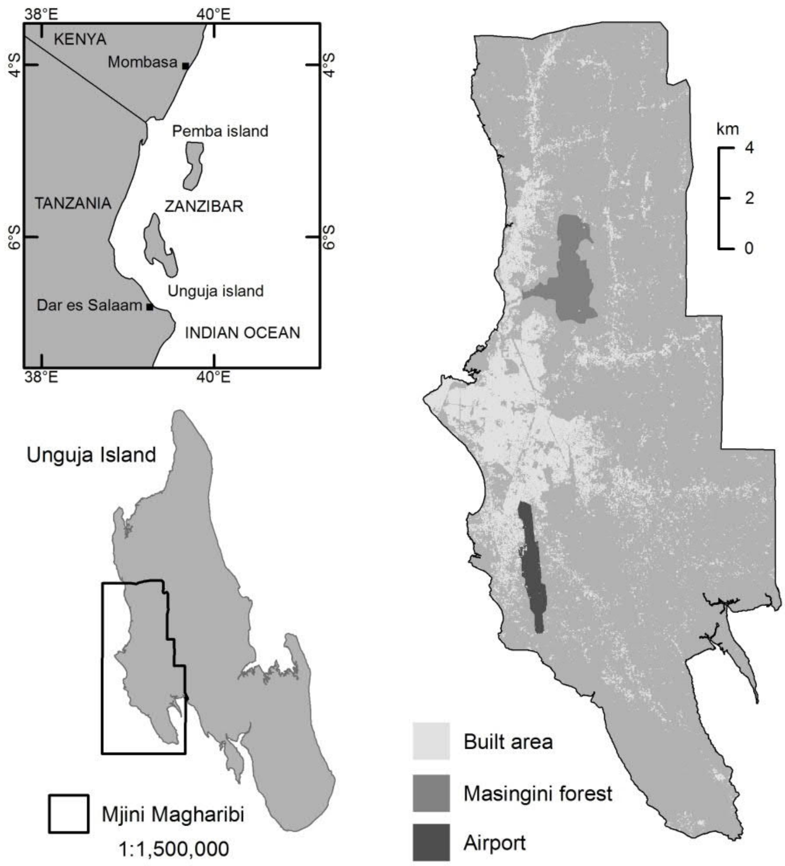


*Figure 1. Study area covered Mjini Magharibi region, which is in the west coast of Unguja Island, Zanzibar, Tanzania. The region consists Zanzibar City, surrounding rural area and Masingini protection forest area.*

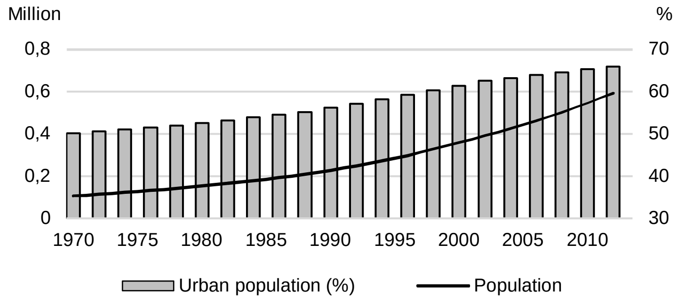


*Figure 2. Population growth of Mjini Magharibi and urbanization of Unguja since 1970 (Thomas 1968, NBS 2004, 2013)*

Zanzibar City's historical center, Stone Town, has been established in early 10th century and it expanded considerably in the 18$^{th}$ century. Already from 19th century the city's official have been worried about its expansion spreading outwards from the center (Haji et. al., 2006; RGZ 2014). Urban expansion has been truly problematic since 1960s as population started to grow rapidly, while at the same time independency allowed freedom of movement, which escalated urbanization (Myers 2008; RGZ 2014). Since mid-1980s, the governmental land delivery system has not been able to meet the needs of new inhabitants, which has caused rapid sprawl of unofficial settlements (Myers, 2008; RGZ, 2012, 2014). Complex land tenure legislation have further increased the problem (Myers, 1996, Törhönen, 1998). In many cases, unofficial housing has spread adjacent to the planned areas that provided public services and infrastructure (RGZ 2014). Especially problematic have been so called "Three Acre Plots"; agricultural land areas confiscated from big landholders, redivided and redistributed to landless farmers in a large-scale land reform between 1965 and 1972. Although, these areas were restricted for agricultural use and selling them was forbidden, many of them ended up as building sites (Törhönen, 1998; Myers 2008). Another local peculiarity has been the strong land user rights of the person who first planted trees on the site, which has caused significant pressure to the agroforestry areas surrounding Zanzibar City (Törhönen 1998; Kukkonen & Käyhkö 2014). In recent decades, the government has tried to limit the encroachment to agricultural land by planning housing areas to shallow coralline soils with limited agricultural potential (Myers 2008; RGZ 2014). Though even in the planned areas, the original dwellers have often sold their valuable planned parcels onwards and squatted nearby areas, which has increased the housing densities beyond what was originally planned (Haji et. al. 2006). Most of these issues are well acknowledged by the governmental planning agencies who are currently updating their land and urban policies to reduce haphazard urban sprawl and limit it negative side-effects (RGZ, 2012, 2014).

### *2.2. Mapping urban growth*

In this study, urban expansion refers to horizontal spread of buildings within the study area, and does not include vertical developments or expansion of other urban elements such as roads, runways or parking lots. Neither does this study separate urban settlements, population or population growth from rural within the study area.

The mapping of urban expansion was done with aerial photographs (0.5 m resolution) of 2004, Ikonos (1 m) satellite image of 2009 (Jan 4) and GeoEye-1 (1.84 m) satellite images of 2013 (Feb 20). The building data of 2004 were mapped as vector polygons by the Department of Survey and Mapping (DoSM). A grid (20 m resolution) was placed over the study area and all the cells either containing or partly covering buildings in 2004 received value 1, while non-built cells were given value 0. The 2004-2009 change mapping was done by first covering the built area of 2004 from the image of 2009, then the remaining study area was visually assed in the scale of 1:2500 and every cell with new buildings were recorded. The 2009-2013 urban expansion was digitized in similar matter, but by covering the built area of both 2004 and 2009.

The created datasets were used to calculate the built area in 2004 and its expansion between 2004 and 2013. The annual rate of urban area expansion ($u$) was calculated with compound interest formula:

$$u = \frac{A_2}{A_1}^{(1/(t_2-t_1)} - 1$$

Where $t_1$ and $t_2$ are the times (year) of the estimates and $A_1$ and $A_2$ the urban area estimates of these years (FAO, 1995). The rate was calculated for the entire study area and for all of its administrative wards.

*2.3. Independent variables*

Independent variables were identified for our model based on the related theory, local circumstances and similar models conducted in other developing countries. Finally, availability of data influenced, which of the variables could be used and we ended up selecting twelve relevant independent variables for the model.

Variables ‘elevation’ (ELE), ‘slope’ (SL) and ‘soil’ (SOIL) were selected to represent the biophysical conditions of the study area. The negative effects of rugged topography to urban expansion were already acknowledged by Harris and Ullmans (1945) and used in many similar models with decent results (Liu, 2009; Arsanjani et. al., 2013). The use of soil variable reflects the local biophysical conditions of Zanzibar, where the two soil types divide livelihood possibilities, which may have later on reflected to urban growth patterns (Hettige 1990). The soil conditions are also linked to local spatial policies as the government has attempted to steer the urban expansion more towards shallow coralline soils with limited agricultural potential (Myers 2004; RGZ 2014). Economic factors are most clearly represented in variables ‘distance to market centers’ (DM) and ‘distance to roads’ (DR), which are proxies of market access (Poelmans & Van Rompaey 2010). ‘Open agricultural areas’ (OA) variable manifests economic circumstances as opportunity cost of urban expansion, but it is also related to local spatial policies forbidding expansion in open agricultural areas (Deng et. al., 2008).

Social factors are acknowledged with variables ‘distance from coast’ (DC), ‘kernel density of buildings’ (KER), ‘distance to buildings (DB) and ‘focal sum of build cells (FOC). The first variable reflects the global trend towards higher quantities of urban expansion in coastal areas, while locally it is linked to development of coastal tourism and high land values, which may have reduced urban expansion in seafront areas (Käyhkö et. al. 2011; Seto et. al. 2011). The 'kernel density of buildings' variable echoes the social and economic factors driving people to inhabit areas with already high population densities (Deng et. al., 2008; Linard et. al., 2011). The two latter variables are manifestations of local social and planning conditions, where houses are built relatively close to each other's due to fragmentation of small land holdings, while on the other hand they are related to spatial interactions, as land use developments attract similar changes in neighboring areas due to Tobler’s first law of geography (Tobler, 1970; Törhönen, 1998; Haji et. al., 2006). The last two variables ‘construction restriction areas’ (RA) and 'three-acre plots' (TAP) represent the local spatial policies that have either obstructed or indirectly promoted urban expansion (Törhönen, 1998; Myers 2008; RGZ 2014).

Variables DC, DB, DR and OA were based on DoSM topographical database, which contained road, building and land cover information digitized from 2004 aerial photographs. Locations of market places and general areas of three-acre plots were based on National Land Use Plan 2012 (RGZ, 2012). ‘Kernel density of buildings’ was created with ArcGIS 10 -tool “Kernel density”, which calculates the amount of build cells weighted by their distance individually for each cell in the study area (Silvermann, 1986). Various kernel thresholds were tested, but the distance threshold of 2.5 km provided best explanatory results in the initial tests. ‘Focal sum of build cells’ was the sum of build cells directly neighboring the cell at focus within 3x3 cell window. The elevation variable was created by calculating Digital Elevation Model (DEM) from 5 meter contours of DoSM database. The DEM was also used to calculate slope for each cell in the grid. The soil variable was derived from the physiographic maps produced by Hettige (1990) by generalizing the soils to two broad categories: deep sandy and coralline soils. The last variable, RA, contained government areas restricted from construction indicated in Zanzibar Master Plan, forest protection areas provided as vector data by Department of Forestry and Non-Renewable Natural Resources as well as airport, park and beach areas of DoSM 2009 database (RGZ, 2014). Variables DB, FOC and KER were updated for modeling years of 2009 and 2013.

Multicollinearity of the independent variables was tested with Pearson’s correlation coefficient (PCC) and Variance Inflation Factor (VIF) analysis. High correlations (PCC > |0.7| or VIF > 5) were not detected and all variables were accepted for the modeling (Dormann et. al. 2013) (Supplementary materials).

### *2.4. Modeling method*

Various modelling methods have been used in the UGPMs, such as Generalized Linear Model (GLM), artificial neural networks, cellular automata and agent-based models (Cheng, 2003; Silva & Wu, 2012;

Triantakonstantis & Mountrakis, 2012; Vermeiren et. al., 2012; Arsanjani et. al., 2013). In this study, the modeling of urban expansion was done with Generalized Additive Model (GAM). GAMs are widely used in modeling of various spatial phenomena and the outcome accuracies are known to be high (Araújo et. al., 2005; Luoto et. al., 2005; Marmion et. al., 2009; Hjort & Luoto, 2011). GAMs extend the range of applications of GLMs by allowing non-parametric smoothers in addition to parametric forms combined with a range of link functions. This allows creation of various response shapes from linear to more complex. (Hastie & Tibshirani, 1990; Guisan et. al., 2002). The strength of GAMs is their ability to deal with highly non-linear and non-monotonic relationships between the dependent and the set of independent variables, which increases the prediction accuracies. Though, as a data-driven technique it has a tendency to over-fit, which can be controlled by limiting the degrees of freedom of the smoothed predictors (Wood, 2008). GAMs of this study were executed with 'gam'-tool of 'mgcv'-package in R software. In all models, the parameter family, defining the distribution of the data, was set to binomial and degrees of freedom were limited to four.

Model was evaluated in a smaller test area, because the used Ikonos (2009) image covered only 52 % of the total study area after clouds were removed. Estimation of past-to-present projection accuracy required observations from at least three time periods and the used datasets were the only available high-resolution images able to provide these observations from Zanzibar. Therefore, the contribution tests and assessment of projection accuracy were done in the test area with models calibrated by 2004–2009 data and tested against real expansion data of 2009–2013, while the entire study area projections were calibrated with 2004–2013 data.

Predicative capabilities of the model and the contributions of individual variables were tested with Area Under the Curve (AUC) and True Skill Statistic (TSS), which are commonly used assessment methods for binary data models (Araújo et. al., 2005; Luoto et. al., 2005; Allouche et. al., 2006; Marmion et. al., 2009). AUC estimates the probability that the model ranks random positive samples higher than random negative ones:

$$AUC = \frac{1}{n_1 n_0} \sum_{i=1}^{n_1} \sum_{j=1}^{n_0} I(p_{1i} p_{0j})$$

$$where, I(p_{1i} p_{oj}) = \begin{cases} 0\ if\ p_{1i} < p_{0j} \\ 0.5\ if\ p_{1i} = p_{0j} \\ 1\ if\ p_{1i} > p_{0j} \end{cases}$$

Where $p_{0j}$ and $p_{1i}$ are the predicted values for the non-development site i and urban expansion site j, while the $n_1$ and $n_0$ are the number of urban expansion and non-development sites (Mason & Graham 2002). AUC values range from 0.5 (equal to random selection) to 1.0 (perfect model). Values between 0.6–0.7 are considered as poor, 0.7–0.8 as fair, 0.8–0.9 as good and 0.9–1.0 as excellent (Swets, 1988; Araújo et. al., 2005). TSS is calculated as the sum of true positive rate (sensitivity) and false positive rate (specificity) minus one:

$$TSS = \frac{n_{11}}{n_{1+}} + \frac{n_{00}}{n_{0+}} - 1$$

Where $n_{11}$ and $n_{00}$ are the number true positive (expansion) and true negative (non-development) observations, while $n_{1+}$ and $n_{0+}$ total observations modeled positive and negative (Allouche et. al., 2006). Calculating TSS requires dividing the modeled data to binary presence-absence classification, which was done by separating the test data to half based on the mode of predicted values. TSS values between 0.2–0.4 are considered as fair, 0.4–0.6 as moderate, 0.6–0.8 as substantial and 0.8–1.0 as perfect (Landis & Koch, 1977). However, the given interpretation ranges of TSS and AUC are merely suggestive.

Past-to-present validation of the models was done with repeated stratified random sub-sampling cross-validation method (Barker et. al., 2014). Sampling increases the distance between individual observations, thus reducing the effects of spatial autocorrelation (SA) and improving model's transferability (Hijmans, 2012; le Roux et. al., 2013). For each model 5% of positive and equal amount negative observations were randomly sampled from 2004-2009 and 2009-2013 urban expansion data. The sampled 2004–2009 data was used to calibrate the model, which was then used to predict urban expansion with the 2009–2013 data. The predicted results were compared to the real expansion of 2009–2013 and AUC as well as TSS were calculated for the prediction results. This cross-validation scheme was then repeated 1 000 times with different permutation for each run and average AUC and TSS values were reported.

The significances of the remaining eleven independent variables were analyzed with alone and drop contributions tests. In alone contributions test, a single variable is used to model urban expansion, while in drop contributions test the single variable is dropped from a model including all other variables. The effect of dropping the variable is estimated against the full model by reducing the drop contribution results from the full model results (Luoto et. al. 2005). The predicative capability of the alone and drop models were estimated with AUC and TSS and the models were subjected to the repeated random sub-sampling cross-validation scheme explained earlier. Variables were selected for the final model with backward stepwise selection process, where in each step the variable with largest negative influence to the overall model was dropped (Kadane & Lazar, 2004). The negative influence was measured by variable's drop contributions TSS result and the stepwise process was continued until no more negative contributions were recorded (Supplementary variables). Based on this process, nine variables were selected for the final model.

The model with the remaining variables was subjected to cross-validation scheme described earlier to calculate the final performance measurement results. After the testing phase, the final model was compiled by first creating 1 000 individual models calibrated with 5 % of positive and equal amount of negative observations selected with stratified random sampling from the full time period of 2004–2013. These sub-models were then averaged with ‘model.avg’-tool of ‘MuMIn’-package in R to create the final model used in predictions of 2013–2030 expansion. This average model however could not be used to calculate the response curves indicating the relationship between dependent and independent continuous variables or coefficients of the dichotomous variables. Therefore, these figures were calculated based on a model calibrated with all observations of the 2004–2013 time period and thus, they are influenced by spatial autocorrelation.

### *2.4. Scenarios of urban growth*

The urban expansion of Zanzibar City was simulated until 2030 with different quantity and spatial pattern scenarios. There were two scenarios for the quantity: ‘business-as-usual growth’ and ‘predicted growth’. The ‘business-as-usual growth’ scenario (1) was based on the annual rate of urban area expansion calculated from the 2004–2013 data of this study, while the ‘predicted growth’ scenario (2) was based on decreased population growth rate (2.7%) of Mjini Magharibi region predicted with cohort-component method for 2012–2037 in Draft National Land Use Plan 2012 (RGZ, 2012). It was seen important to include the scenario with decreased population growth rate as global studies suggest it to be the main factor determining the quantity of urban expansion in Africa (Seto et. al. 2011). However, the results of this study indicate that the annual population growth rate (4.2 % in 2002–2012) and measured annual rate of urban expansion (3.8 % in 2004–2013) vary slightly, probably due to vertical building, densification and changes in household sizes (NBS 2014). Therefore, the predicted future population growth rate of NLUP (2012) was adjusted according to this ratio (3.8 % / 4.2 % * 2.8 % = ~2.4 %) to 2.4 % annual rate of urban expansion for the ‘predicted growth’ –scenario.

Six scenarios influencing the spatial pattern of urban expansion were developed. Again, the first scenario (A) was ‘business-as-usual pattern’, which was based on the same setting of explanatory variables as used in the original model. The five other scenarios were developed based on spatial plans recommended by Department of Urban and Rural Planning in their most recent and valid policy reports. Two scenarios were based on *Urban Development Management Approach Report* (RGZ, 2014): ‘Urban nodes’ scenario (B) seeks to establish eight new urban centers to existing suburbs, while in ‘infill’ scenario (C) certain government and military areas are opened for infill. Two scenarios were developed according to *Draft National Land Use Plan 2012* (RGZ, 2012): ‘Road development’ scenario (D) aims to direct urban sprawl by building three new roads in the city region, while ‘airport transfer’ scenario (E) relocates Abeid Amani Karume International Airport to less valuable scrubland 20 kilometers away from the city. Final ‘combined plans’ scenario (F) merges all of the four previously described scenarios into one. The alternative spatial pattern scenarios were developed to estimate how effectively these plans would direct urban expansion, which was measured by calculating the percentage of expansion area varying from the ‘business-as-usual pattern scenario’.

The scenario simulations were created by fitting the already established model to the unbuilt cells of the study area with ‘predict’-tool in R and selecting cells with highest predicted values equaling the area defied by the quantity scenarios. Combining the quantity (1 & 2) and spatial pattern (A-F) scenarios created altogether twelve simulations of urban expansion between 2013 and 2030.

## 3. Results

### *3.1. Patterns of urban expansion in Zanzibar City*

The built area of Zanzibar City was 40.7 km$^2$ in 2004 and it increased by 40% to 56.9 km$^2$ in 2004–2013 (Figure 3). The annual rate of urban area expansion was 3.8% during this period. The wards at the outskirts of the city limit had extremely high annual urban expansion rates (5-10%), while the rates were low (0.5-3.0%) in the wards at city center and rural areas.

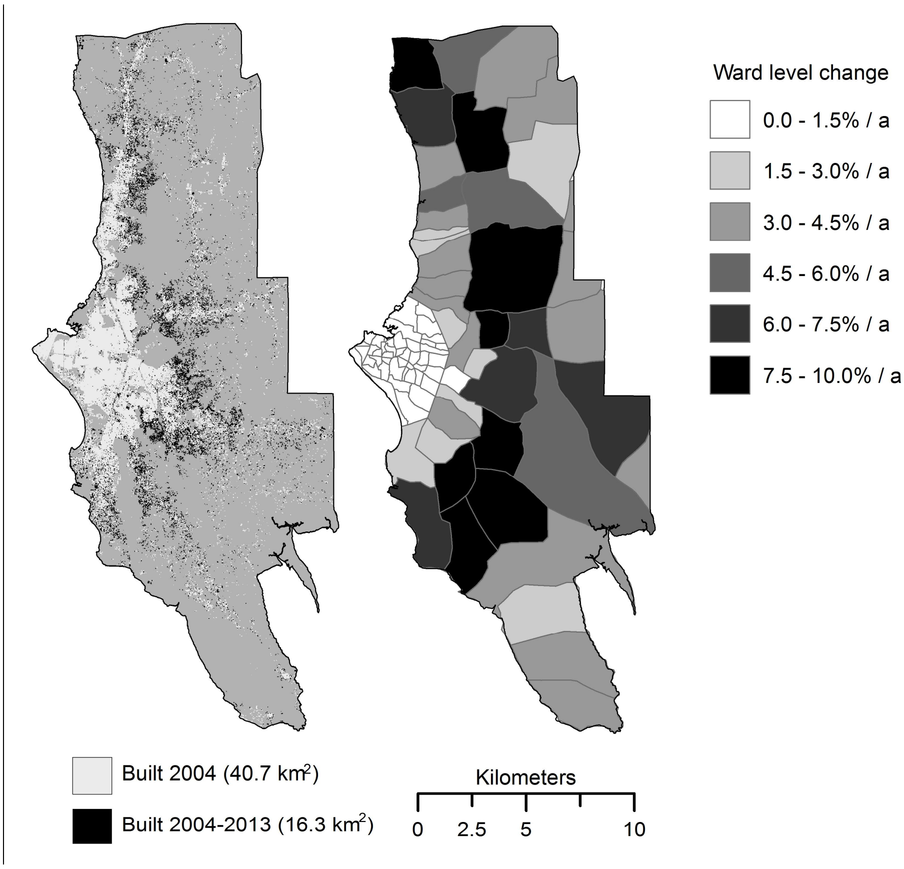


*Figure 3. Built area expansion of Mjini Magharibi between 2004 and 2013 and the annual urban expansion rates calculated for study area wards.*

The final cross-validated model has average AUC of 0.855 and TSS of 0.568, which indicates that the predictive accuracy of the model is reasonably good. Visual estimation of the results revealed that majority of incorrectly classified cells are either dispersed settlements far from city center or unbuilt cells within otherwise densely built areas.

The drop contribution test results suggest that variables ‘construction restriction areas’, ‘distance to buildings’ and ‘kernel density of buildings’ have high influence on model performance, while ‘distance to markets’, ‘focal sum of build cells’ and ‘distance to roads’ have moderate effect (Table 1). Variables ‘three-acre plots’, ‘elevation’ and ‘open agriculture areas’ have minor influence on the model performance, while variables ‘slope’, ‘distance to coast’ and ‘soil’ were removed from the model already in variable selection phase due to negative impact (Supplementary variables).

*Table 1. Alone and drop contributions test results of the variables used in final model. Variables are sorted based on drop contribution TSS results.*

| | Alone | | Drop | |
|---|---|---|---|---|
| Variable | AUC | TSS | AUC | TSS |
| RA | 0.577 | n/a | 0.0114 | 0.0291 |
| DB | 0.813 | 0.493 | 0.0074 | 0.0183 |
| KER | 0.739 | 0.367 | 0.0066 | 0.0172 |
| DM | 0.663 | 0.276 | 0.0009 | 0.0064 |
| FOC | 0.745 | 0.389 | 0.0076 | 0.0062 |
| DR | 0.638 | 0.193 | 0.0001 | 0.0054 |
| TAP | 0.578 | n/a | 0.0005 | 0.0031 |
| ELE | 0.601 | 0.164 | 0.0000 | 0.0010 |
| OA | 0.549 | n/a | 0.0010 | 0.0006 |

The smooth functions of independent variables indicated varied responses (Figure 4). The variable ‘distance to buildings’ shows a fluctuating response where the probability of becoming built is highest at immediate vicinity of other buildings, then decreases almost linearly until 500 meters, rises again slightly until 1200 meters and then rapidly drops after that. This slight rise after 500 m is most likely caused by unexpectedly behaving isolated observation at these distances. The response of ‘kernel density of buildings’ suggests that the probability of urban expansion is lowest when the density is zero and peaks at 500 buildings/ $km^2$. In the response shape of variable ‘distance to markets’ highest probability of becoming built is achieved at the immediate vicinity of the markets, which after the probability steadily declines until 10 km. The response of ‘focal sum of build cells’ shows almost a linear increase, indicating that risk of becoming built is highest when the cell is surrounded by already existing buildings. The response shape of ‘distance to roads’ shows that areas at immediate vicinity of roads being preferred for urban expansion. However, this is shown to have only minor impact and remaining relatively stable until 2000 meters from roads, after which it declines rapidly. The variable ‘elevation’ has a fluctuating response that is highest around 20 meters and then again at maximum elevation of 100 meters. The coefficient of variable ‘construction restriction areas’ is -2.01, which indicates that the probability of urban expansion is significantly lower in these areas than outside them. The ‘TAP’ variable has a coefficient of 0.18 indicating that urban expansion is slightly more common in three-acre plots than outside them, while the coefficient of variable ‘OA’ (-0.93) indicates that probability of expansion is lower within agricultural areas.

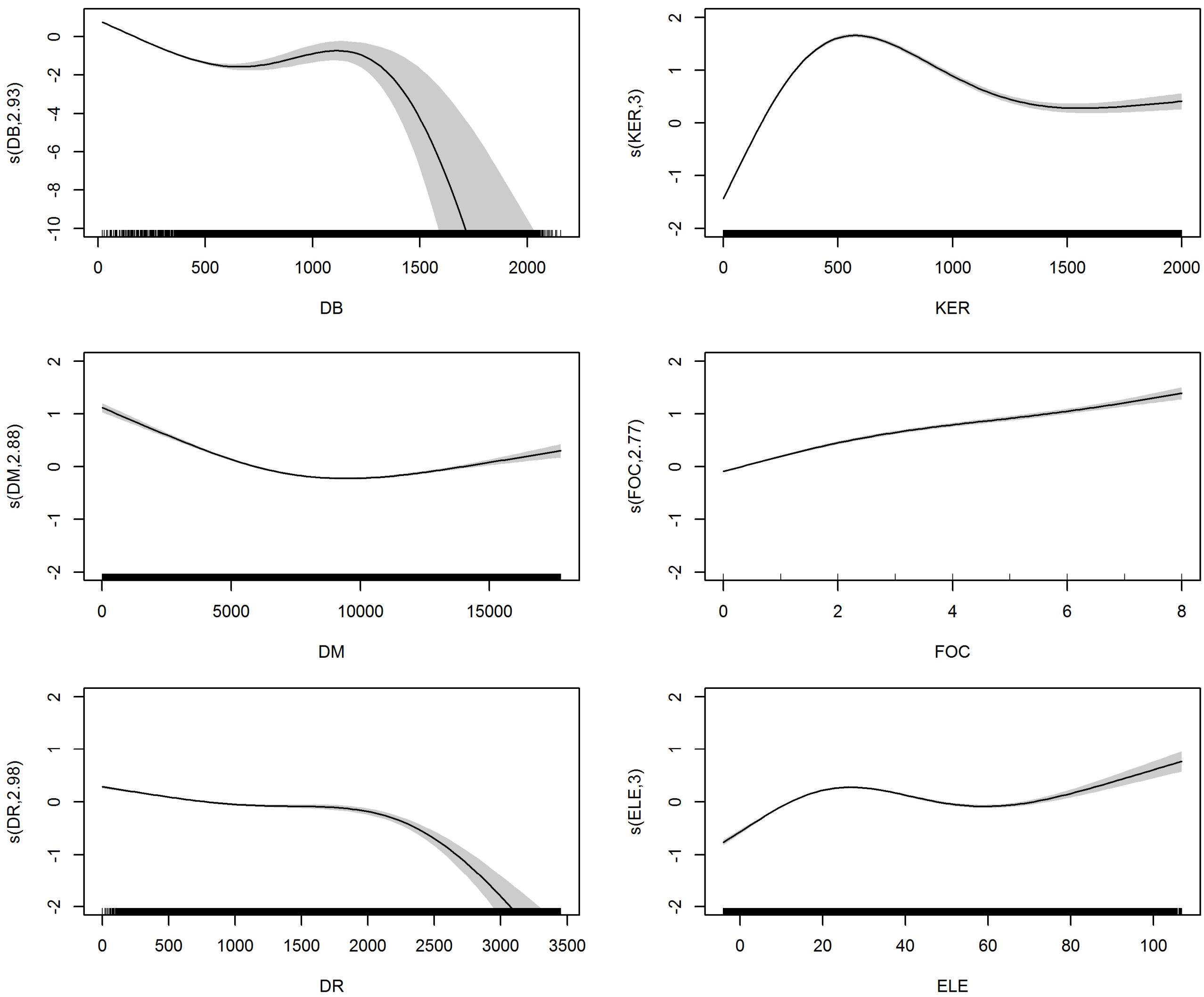


*Figure 4. Variable smooth functions of the final generalized additive model of urban expansion plotted on the scale of the linear predictor. The grey areas are 95% confidence intervals; y-axis represents the effect of the respective variable; the figure in y-axis title indicates the estimated degrees of freedom and s the smooth term of GAM.*

### *3.2. Modeled urban area of 2030*

Based on ‘business-as-usual growth -scenario the built area will be 107.1 km$^2$ in 2030 (Figure 5). This would mean 88% increase from 2013. In the more optimistic ‘predicted growth’ -scenario, the built area would increase by 50% to 85.2 km$^2$.

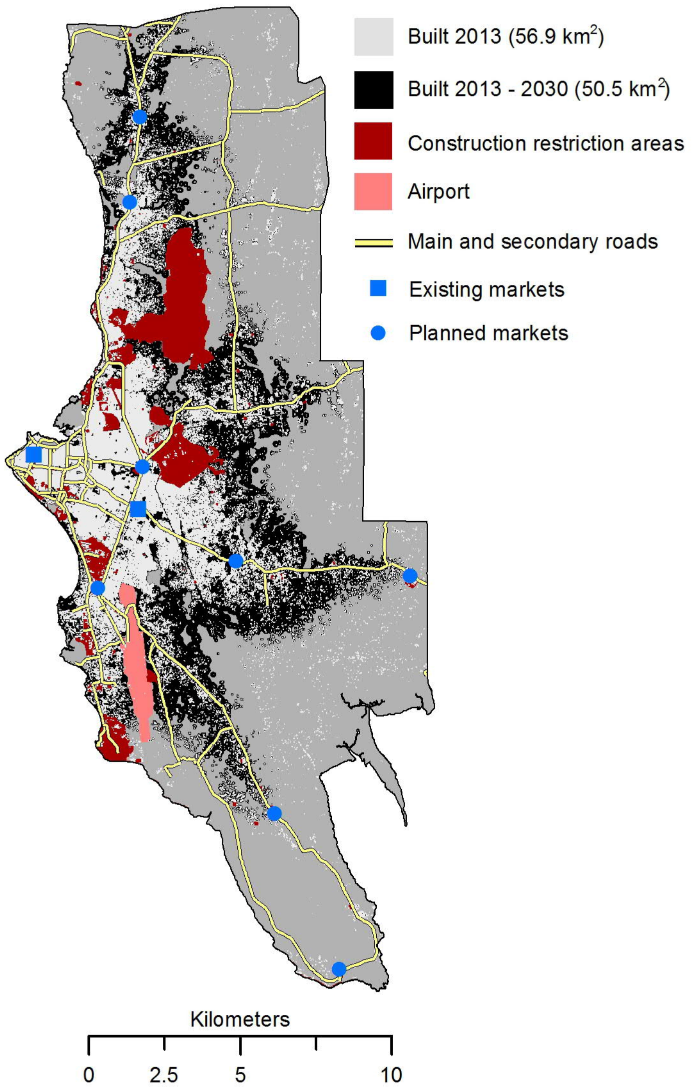


*Figure5. Predicted business-as-usual built area expansion of Mjini Magharibi between 2013 and 2030 displayed with selected variables influencing the expansion patterns.*

Based on visual interpretation of the business-as-usual growth and pattern scenarios, the urban expansion is expected to happen through densification of already established, but sparsely built neighborhoods at the outskirts of the current city. Urban expansion is predicted to decline in some of the wards having highest growth rates between 2004 and 2013, as majority of their open spaces become settled. Simultaneously, sprawl pushes towards new wards further away from the city center. New settlements are also mainly established into agroforest and fruit tree plantation areas.

When the alternative planning actions are compared to the ‘business-as-usual pattern’, the ‘urban nodes’ scenario has the highest effect on directing urban expansion (Table 2). If new urban nodes would exists it is expected to shift the location of 7.7% of new buildings built between 2014 and 2030 if the quantity of urban growth remains the same, and 13.0% if urban growth declines according to the ‘predicted growth’ scenario. Also the ‘infill’ and ‘road development’ scenarios have some effect on directing urban sprawl, while the effects of ‘airport transfer’ scenario are rather limited. When these planning approaches are merged to ‘combined plans’ scenario it is expected to influence the location of 10–15% of new buildings depending on the quantity of the growth.

*Table 2. Urban expansion patterns (2013–2030) produced by alternative spatial scenarios are compared to ‘business-as-usual pattern’ scenario to estimate their impact on directing urban expansion.*

| | Quantity scenarios | |
|---|---|---|
| Spatial scenarios | Business-as-usual growth | Predicted growth |
| Urban nodes | 7.7 % | 13.0 % |
| Infill | 5.0 % | 5.4 % |
| Road development | 2.2 % | 3.4 % |
| Airport transfer | 2.1 % | 0.8 % |
| Combined plans | 10.4 % | 15.3 % |

## 4. Discussion

### *4.1. Urban expansion of Zanzibar City*

Zanzibar City seems to be following the patterns of rapid urbanization and extensive urban expansion typical to Sub-Saharan cities (Angel, 2011; Linard et. al., 2013; ADB, 2014; UN, 2014). With current growth rate, the population would double every 18 years. The mere magnitude of absolute population growth has made the city to sprawl rapidly and the annual rate of urban area expansion (3.8%) is only slightly less than the annual population growth rate (4.2%). This indicates that the urban area expansion is almost linearly linked with population growth in Zanzibar City; opposite to the studies theorizing that population growth will cause exponential urban expansion in Africa as densities of built-up areas decline (Angel et. al., 2010, 2011).

With the current urban expansion rate, the city would nearly double its spatial extent by 2030. However, the annual population growth rate has already started to decline. The rate declined from 4.5% to 4.2% in Mjini Marharibi region and from 3.1% to 2.8% in entire Zanzibar between last two intercensal periods (NBS, 2013). Also the cohort-component population projections of NLUP (2012) predicted the population growth rate to be 2.7% between 2012 and 2037, indicating that there is a real turn towards lower population growth rates. As urban population growth is considered as the main driver of urban expansion quantity in Africa, this decline will most likely reduce the extent of urban expansion significantly (Seto et. al. 2011). Though, even if the annual urban expansion rate would be as low as 2.4% between 2013 and 2030, the urban area would still increase by 50% during this time.

Majority of urban expansion in Zanzibar City takes place in suburbs outside the city center. The response shape of the *‘kernel density of buildings’* variable supports this observation as its peak is not in the most congested core or sparse rural areas, but somewhere in the middle. Also the ward-level growth rates show fastest expansion in areas 5 to 10 km from the center, while the growth rates are modest in the city center and in rural areas. However, this suburbanization in Zanzibar might be rather caused by land scarcity of the center than push factors created by congestion and poor quality of housing as the theories suggest (Chin, 2002; Leao et. al., 2004). For example, the response shape of *'distance to markets'* still suggest that expansion would happen in areas as close as possible to the main market centers, which is a typical pattern in the developing world, but significantly sized non-built areas close to market centers are rare or restricted for government or military usage in Zanzibar (Taubenböck et. al., 2011; Doan & Oduro, 2012; Vermeiren et. al., 2012; Arsanjani et. al., 2013; Linard et. al., 2013). There were no signs of counterurbanization where urban area densities would decline and population in core or suburbs would move towards rural areas (Leao et. al., 2004; Linard et. al., 2013).

The spatial pattern urban expansion of Zanzibar City is largely defined by the pattern of already established buildings, which is indicated by the high importance of variables DB and KER as well as moderate effect of variable FOC in the contributions tests. This is hardly surprising, as it well known that forms of land use attract similar uses in nearby areas (Hoyt, 1939; Harris & Ullmans, 1945; Poelmans & Van Rompaey, 2010). Also a continental study by Linard et. al. (2013) suggests amount of neighboring urban areas to be the most important spatial indicator for future urban expansion in Africa and case studies from various developing countries have shown similar patterns (Doan & Oduro, 2012; Vermeiren et. al., 2012; Arsanjani et. al., 2013). However, the influence is rarely as emphatic as in Zanzibar. This is most likely caused by the local social and planning conditions, where small land holdings provided in the land reform are split to even smaller parcels and planned parcels are sold onwards as previous owners squat nearby areas (Törhönen, 1998; Haji et. al., 2006; Myers, 2008; RGZ, 2014). Also land use constraints have relatively high influence on the growth patterns based on the contributions tests, which suggests that the restrictions are well respected, at least when they are enforced with fences or by the military.

The importance of 'distance to markets' and 'distance to roads' variables have already been acknowledged by the early sociological and economic models as they manifest market access (Von Thünen, 1826; Burgess, 1925; Hoyt, 1939; Deng et. al., 2008; Poelmans & Van Rompaey, 2010) and they have been among the most important factors in many modern UGPM studies (Hu & Lo 2007; Doan & Oduro, 2012; Vermeiren et. al., 2012; Arsanjani et. al., 2013; Linard et. al., 2013). In the case of Zanzibar City, the variables were moderately important, but clearly not as influential as the factors related to already existing building patterns and restrictions. It could be that market access and road networks influence the model indirectly by directing the spatial patterns of already established buildings. This is supported by the relatively high negative correlation between variables DM and KER (-0.63) (Supplementary materials).

Besides these variables, other factors either had minor, negligible or even negative impact on the models. Coastal location has been highly significant in global studies, but locally it did not influence the expansion patterns, which is somewhat unexpected in island settings (Seto et. al. 2011). It might be that government placed restrictions and high land prices counterbalanced the pull factors of the coast, leaving the variable insignificant, but further empirical evidence would be needed. Situation was similar with open agricultural areas as they did not substantially attract or repel urban expansion according on the contributions tests. This is somewhat alarming as building is generally prohibited from agricultural lands and the variable was assumed to have clear impact on urban expansion (Törhönen, 1998; Myers 2008). On the other hand, the Three Acre Plots generally assumed to be largely fragmented to housing parcels showed to be only a very minor, almost negligible, pull factor for urban expansion (Törhönen, 1998; Myers, 2008). Despite the radical impact of soil on natural landscapes and livelihood opportunities, it had no impact in the prepared UGPM. This could suggest that the government efforts attracting inhabitants to infertile coralline soils have been at least somewhat successful as otherwise urban expansion could be assumed to concentrate to the sandy soils closer to the current urban area (Myers 2004; RGZ 2014). Topographical variables, which are quite significant in some mountainous settings, had expectedly low contributions in generally flat Zanzibar (Arsanjani et. al., 2013).

Based on the mapping and the created scenarios, urban expansion has and continues to happen mainly at the expense of surrounding agroforests and fruit tree plantations. Majority of Zanzibar's biomass is in these forests and urban growth has already been identified as one of main causes of deforestation on the Island (Kukkonen & Käyhkö, 2014). The heavy burden on agroforests is most like due to the historical land regulations and laws allowing more private usage rights to areas where trees have been planted (Törhönen, 1998). Because of this preference on agroforests, the negative environmental effects relevant to many other cities such as loss of natural forests, open cropland and wetlands have been less evident in Zanzibar (Eigenbord, et. al., 2008; McDonald et. al., 2011; Vermeiren et. al., 2012).

*4.2. Planning against sprawl*

The Government of Zanzibar is currently modifying its planning policies to reduce urban sprawl and its negative effects (RGZ, 2012, 2014). One of the main proposed planning approaches is to direct the urban expansion to already existing neighborhoods and areas with limited agricultural capacity by establishing eight new urban nodes/centers with services to current suburbs (RGZ, 2014). These kinds of satellite cities and other clustered developments have been widely promoted as one of the main solutions to the urbanization dilemma of Africa (Watson, 2013; UN-Habitat, 2014). In theory, these satellite cities would supply the inhabitants with majority of their needs, thus reducing a need for transportation and improving the general living conditions, but they have been criticized for being planned mainly for the well-of segments of the society, generating traffic and being followed by informal development outside planned areas (Alaci, 2010; Vermeiren et. al., 2012; Watson, 2013; UN-Habitat, 2014). Our results show that distance to market centers had moderate contributions in the urban growth model, which suggest that urban centers have some effect attracting urban expansion in Zanzibar. Also the 'urban nodes' scenario had the highest influence on directing urban sprawl from the tested alternative planning approaches. However, the results were only moderate, therefore setting up new urban nodes is not likely to be sufficient alone in reducing urban sprawl and other approaches are also needed.

Another suggested plan is to open 6.3 $km^2$ of government and military areas to housing construction (RGZ, 2014). The related alternative scenario 'infill' suggests that only 2.9 $km^2$ of these areas would be built by 2030 with current growth rates, which is merely 6% of anticipated total expansion. The overall impact of this activity would be quite limited, but these areas could be suitable targets for well-planned development of multi-story housing and services, which would lead the way towards more compact vertical city. Draft National Land Use Plan 2012 presents an idea of relocating the airport away from the city region (RGZ, 2012). This is shown to have limited influence on directing the urban sprawl, especially considering the cost of the activity. Our results also indicate that new roads have little impact on urban sprawl, although they could improve the living standards otherwise.

The tested planning policies, even when they were combined, had relatively minor impact on directing urban sprawl. Therefore, also other planning approaches directing expansion as well as densification of the existing urban area are needed. One of the government's main planning tool for densification is to promote vertical building (RGZ, 2014). The potential of vertical development is extremely relevant as majority of the buildings are currently single-story detached houses. Promotion of vertical development could be accompanied with improvements in land ownership and registration to support sustainable housing planning and tenure. However, the building patterns are so dense in some of the unplanned areas that multistory buildings cannot be easily built on individual parcels. Even with these limitations, the government should continue and increase its support to vertical development as by doing so it can reduce urban expansion considerably.

Building restrictions are shown to be relatively effectual in Zanzibar and possibilities of expanding these restrictions in form of Urban Growth Boundary (UGB) could be investigated. UGB is an outer edge of urban expansion, beyond which housing should no spread (Jun, 2004; Tayeebi et. al., 2012). The administrational boundaries of Mjini Magharibi do not correspond with the real boundary of the city region and UGB would provide a tool against sprawl, without modifying the current administrative entities. Planning policies of Zanzibar do not include UGB at the moment, but it could be introduced through legislation, allowing a mandate for the government to take action against any development happening outside the boundary. Urban growth models, such as the ones presented here, could be used to define the UGB (Tayyebi et. al., 2011). Unfortunately, the UGB might have serious negative effects on the already marginalized inhabitants dependent on unofficial housing at the outer edges of the city. UGBs have also been criticized for inefficiency (Jun, 2004; Tayeebi et. al., 2012). This could be a major problem also in Zanzibar, as implementation of abstract growth boundary is far more challenging than securing the existing physically defined restriction areas.

Urban planning of Zanzibar City has started already in 1830s, first master plan was made in 1920s and urban sprawl has been on the agenda since 1980s (Törhönen, 1998; Myers, 2008). The problem has never been lack of planning, but rather implementation and resources. The governmental land planning system has simply not been able to provide enough planned housing for the rapidly growing population (Törhönen, 1998; Myers, 2008; RGZ, 2012, 2014). This is an acknowledged problem not only in Zanzibar, but generally in Sub-Saharan Africa (Odendaal, 2012; UN-Habitat, 2014). The implementation inefficacy of African urban planning has spurred demands to revitalize traditional planning procedures. Suggested approaches of "new planning" usually consist acceptance of informal settlements, gradual improvement of the informal areas and participatory planning (Odendaal, 2012; Ngau, 2013; UN-Habitat, 2014). Functional participatory planning procedures have already been set in forest sector of Zanzibar and there is genuine interest to include them into the toolbox of urban planners (RGZ, 2012; Eilola et. al., 2014). Also the attitudes towards informal settlements have been changing, but official acceptance has not been given and improvement plans are still missing (RGZ, 2012, 2014). The potential of all possible tools, traditional or new, should be unconditionally investigated as there is a real change that Zanzibar City will continue its uncontrollable growth until the second half of this century.

*4.3. Methodological considerations*

Mapping of urban expansion in this study was based on high-resolution remote sensing data acquired by the Revolutionary Government of Zanzibar with the support of various development and research projects. This allowed more accurate detection of urban growth and thus, more accurate model, than using freely available satellite data with lower resolution. However, use of freely available data should be promoted for continuance purposes, as it is unlikely that the Government of Zanzibar is able to provide high-resolution images in the future without international funding.

This study attempted to base the selection of independent variables on related theories, knowledge of local policies and conditions as well as similar models. However, it is eventually the quality and availability of spatial data that dictates what can be used in the models and the availability of data is generally poor in developing countries (Barredo et. al. 2003). For this reason, UGPMs are often conducted with similar, simple, easily available and largely biophysical or infrastructure related variables. This can create an expectancy bias where UGPMs are built on suboptimal sets of variables, because so have been done in previous studies, instead of collecting and developing variables with more explanatory power. Also the used variables are often mere proxies of other more complicated driving forces, which cannot be directly measured (Poelmans & Van Rompaey, 2010; Triantakonstantis & Mountrakis, 2012). Therefore, it is important to be cautious when making far-reaching assumptions based on model variable results and to test new, even seemingly unimportant, variables in UGPMs. For example, reliable and systematically collected socio-economic information would have most likely improved the projection accuracies of this study significantly.

Even though, the UGPMs are rather crude simplifications of complex urban expansion, their use can be justified with high predicative accuracy, as in the case of the created model (Triantakonstantis & Mountrakis, 2012; Linard et. al., 2013). The model's accuracy was reasonably good when compared to real future data and can be therefore reliably used to predict urban expansion. However, the projection accuracy and the model in general could have been improved with few actions. Firstly, the model could have been made gradual by predicting urban expansion one year at a time and then updating building pattern related variables (DB, KER & FOC). Though, this gradual approach would have increased the computational requirements enormously. Secondly, the model was limited in its approach towards spatial autocorrelation. Random subsampling of observation was conducted to reduce the effects of SA (Hijmans, 2012; le Roux et. al., 2013). However, the effectiveness of this approach was not measured and therefore, the results may be still influenced by spatial autocorrelation. Alternative approaches, such as autocovariate models, could have been more effective in reducing SA (Dormann et. al. 2007). Thirdly, the effects of the alternative planning scenarios were assessed merely quantitatively, though it would have been more meaningful to estimate them qualitatively by measuring what kind of land use changes are reduced by each scenario.

The results of this study emphasize the spatial complexity of urban expansion as local reciprocal interactions of the biophysical, social, economic and policy factors created an outcome unique to Zanzibar City (Lambin et. al., 2001; Cheng, 2003). Some factors proven important in global studies had negligible impact in Zanzibar, while other factors were far more emphatic than elsewhere. This underlines the need of local calibration of urban expansion models. Although, African cities have been well represented in global and regional urban expansion studies, more local UGPMs targeting individual countries or cities would be needed to provide more detailed and context relevant information required by urban planners and decision makers (Taubenböck et. al., 2011; Seto et. al. 2011; Linard et. al., 2013).

The UGPMs are not only valuable tools for predicting future urban expansion, but they can be also used to test the effects of alternative planning scenarios directing urban expansion as done in this study. Scientifically based information on the issue is extremely valuable for decision makers, especially in Sub-Saharan Africa where the urban growth rates are high and resources for planning and implementation limited (UN-Habitat, 2014). However, the increasing amount of information should be accompanied by improved transition of the UGPMs from model developers to end-users (urban planners/decision makers), as currently many adequate models are underutilized in the planning process despite their acknowledged value. To improve this, the end-users should be involved in the model development as early as possible and the model developers should provide guidance in the use of their models even after the main scientific results have been published. Hopefully, a more proactive approach from both sides will solve this mismatch, as we genuinely believe that UGPMs are highly valuable tools for 21st century urban planning.

## Acknowledgements

We thank Departments of Urban and Rural Planning, Survey and Mapping as well as Forestry and Non-Renewable Natural Resources of the Revolutionary Government of Zanzibar, University of Turku, Department of Geography and Geology (Academy of Finland project 132819) as well as Sustainable Management of Land and Environment Programme (SMOLE I and II) for providing the data and information that was essential for this research. Especially, we would like to thank Department of Urban and Rural Planning for guiding us in production of the alternative urban expansion scenarios. We would also like to thank the two anonymous reviewers who kindly provided their time for reviewing this study.

**References:**


African Development Bank (ADB) (2014). *Tracking Africa's Progress in Figures.* 39 p. ADB, Tunis.

Alaci, D.S.A. (2010). Regulating urbanization in Sub-Saharan Africa through cluster settlements: Lesson from urban managers in Ethiopia. *Theoretical and Empirical Researchers in Urban Management* 5:14, 20–34.

Allouche, O., Tsoar, A., & Kadmon, R. (2006). Assessing the accuracy of species distribution models: prevalence, kappa and the true skill statistic (TSS). *Journal of Applied Exology* 43, 1223–1232.

Angel, S., Parent, J., Civco, D.L. & Blei, A. (2010). *The Persistent Decline in Urban Densities: Global and Historical Evidence of 'Sprawl'.* 151 p. Lincoln Institute of Land Policy, Cambridge.

Angel, S., Parent, J., Civco, D.L., Blei, A. & Potere, D. (2011). The dimensions of global urban expansion: Estimates and projections for all countries, 2000–2050. *Progress in Planning* 75:2, 53–107.

Araújo, M., Pearson, R., Thuiller, W., & Erhard, M. (2005). Validation of species-climate impact models under climate change. *Global Change Biology* 11, 1–10.

Arsanjania, J. J., Helbichb, M., Kainza, W. & Bolooranic, A. D. (2013). Integration of logistic regression, Markov chain and cellular automata models to simulate urban expansion. *International Journal of Applied Earth Observation and Geoinformation* 21, 265–275.

Barker, N.K.S., Cumming, S.G., & Darveau, M. (2014). Models to predict the distribution and abundance of breeding ducks in Canada. *Avian Conservation and Ecology* 9:2:7.

Barredo, J. I., Demicheli, L., Lavalle, C., Kasanko, M., & McCormick, N. (2004). Modelling future urban scenarios in developing countries: An application case study in Lagos, Nigeria. *Environment and Planning B* 31:1, 65–84.

Batty, M. (1995). New ways of looking at cities. *Nature* 377, p. 574.

Batty, M. (2008). The Size, Scale, and Shape of Cities. *Science* 319:5864, 769–771.

Burgess, E. (1925). The Growth of the City: An Introduction to a Research Project. In Park, R.E., Burgess, E., & McKenzie, R. (Eds.). *The City.* University of Chicago Press, Chicago. pp. 47–62.

Cheng, J. (2003). *Modelling Spatial and Temporal Urban Growth.* 202 p. ITC, Enschede.

Chin, N. (2002). *Unearthing the roots of urban sprawl: a critical analysis of form, function and methodology,* 44 p. University College, London.

Cohen, B. (2006). Urbanization in Developing Countries: Current Trends, Future Projections, and Key Challenges for Sustainability. *Technology in Society* 28, 63–80.

Couclelis, H. (2005). Where has the future gone? Rethinking the role of integrated land-use models in spatial planning. Environment and Planning A, 37:8, 1353–1371

Doan, P. & Oduro, C.Y. (2012). Patters of Population Growth in Peri-Urban Accra, Ghana. *International Jourbal of Urban and Regional Research* 36:6, 1306–1325.

Deng, X., Huang, J., Rozelle, S., & Uchida, E. (2008). Growth, population and industrialization, and urban land expansion of China. *Journal of Urban Economics 63*, 96–115.

Dormann, C., McPherson, J., Araujo, M., Bivand, R., Bolliger, J., Carl, G., Davies, R., Hirzel, A., Jetz, W., Kissling, D., Kuhn, I., Ohlemuller, R., Peres-Neto, P., Reineking, B., Schröder, B., Schurr, F., & Wilson, R. (2007). Methods to account for spatial autocorrelation in the analysis of species distributional data: a review. *Ecography* 30, 609–628.

Dormann, C., Elith, J., Bacher, S., Buchmann, C., Carl, G., Carré, G., García Marquéz, J., Gruber, B., Lafourcade, B., Leitão, P., Münkemüller, T., McClean, C., Osborne, P., Reineking, B., Schröder, B., Skidmore, A., Zurell, D., & Lautenbach, S. (2013). Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. *Ecography* 36:1, 27–46.

Dye, C. (2008). Health and urban living. *Science* 319:5864, 766–769.

Guisan, A., Edwards, T., Jr., & Hastie, T. (2002). Generalized linear and generalized additive models in studies of species distributions: setting the scene. *Ecological Modelling* 157, 89–100.

Guneralp, B., & Seto, K. C. (2008). Environmental impacts of urban growth from an integrated dynamic perspective: A case study of Shenzhen, South China. *Global Environmental Change – Human and Policy Dimensions*, 4:18, 720–735.

Eigenbrod, F., Bell, V.A., Davies, H.N., Heinemeyer, A., Armsworth, P.R., & Gaston, K.J. (2008) The impact of projected increases in urbanization on ecosystem services. *Proceedings. Biological sciences/The Royal Society* 278:1722, 3201–3208.

Eilola, S., Fagerolm, N., Mäki, S., Khamis, M. & Käyhkö, N. (2014). Realization of participation and spatiality in participatory forest management – a policy–practice analysis from Zanzibar, Tanzania. *Journal of Environmental Planning and Management* 58:7, 1242–1269.

Eyoh, A., Olayinkab, D. N., Okwuashid, P. N. O., Isonge, M. & Udoudof D. (2012). Modelling and Predicting Future Urban Expansion of Lagos, Nigeria from Remote Sensing Data Using Logistic Regression and GIS. *International Journal of Applied Science and Technology* 2:5, 1–9.

Haji, H.A., Azzan, R.M. & Ufuzo, S.S. (2006). *Evolution of Spatial Planning in Zanzibar and its Influence.* 13th FIG Congress TS:36 – Spatial Planning Practices: Urban Renewal Tools and PPP, 15 p.

Harris, C., & Ullman, E. (1945). The Nature of Cities. *The Annals of the American Academy of Political and Social Science 242*, 7–17.

Hastie, T., & Tibshirani, R. (1990). *Generalized additive models*. 35s p. Chapman & Hall, London.

Hettige, M.L. (1990). *Land evaluation and land suitability classification – Unguja & Pemba Island.* Rome: Food and Agriculture Organization of the United Nations.

Hijmans, R. J. (2012). Cross-validation of species distribution models: removing spatial sorting bias and calibration with a null model. *Ecology* 93, 679–688.

Hjort, J. & Luoto, M. (2011). Novel theoretical insights into geomorphic process–environment relationships using simulated response curves. *Earth Surface Processes and Landforms* 36, 363–371.

Hoyt, H. (1939). *The Structure and Growth of Residential Neighborhoods in American Cities.* 178 pp. United States. Federal Housing Administration, Washington D.C.

Hu, Z., & Lo, C.P. (2007). Modeling urban growth in Atlanta using logistic regression. *Computers, Environment and Urban Systems* 31, 667–688.

Jun, M–J. (2004). The effects of Portland's Urban Growth Boundary on urban development patterns and commuting. *Urban studies* 41:7, 1333–1348.

Kadane, J.B., & Lazar, N.A. (2004). Methods and Criteria for Model Selection. *Journal of the American Statistical Association* 99:465, 279–290.

Kamete, A. Y. (2011). Interrogating planning's power in an African city: Time for reorientation? *Planning Theory* 11, 66–88.

Keiner, M., Koll-Schretzenmayr, M., & Schmid, W. A. (2005*). Managing Urban Futures: Sustainability and Urban Growth in Developing Countries*. 277 p. Ashgate Pub Co, London.

Kukkonen, M. & Käyhkö, N. (2014). Spatiotemporal analysis of forest changes differences between forest use regimes: Case study from Zanzibar, Tanzania. *Applied Geography* 55, 193–202.

Käyhkö, N., Fagerholm, N., Asseid, B., & Mzee, A. (2011). Dynamic land use and land cover changes and their effect on forest resources in a coastal village of Matemwe, Zanzibar, Tanzania. *Lans Use Policy,* 28:1, 26-37.

Landis, J.R., & Koch, G.G. (1977). The measurement of observer agreement for categorical data. *Biometrics* 33:1, 159–174.

Lambin, E.F., Turner, B.L., Geist, H., Agbola, S., Angelsen, A., Bruce, J., Coomes, O., Dirzo, R., Fischer, G., Folke, C., George, P.S., Homewood, K., Imbernon, J., Leemans, R., Li, X., Moran, E., Mortimore, M., Ramaskrishnan, P.S., Richards, J., Skånes, H., Steffen, W., Stone, G., Svedin, U., Veldkamp, T., Vogel, C., & Xu, J. (2001). The causes of land-use and land-cover change: Moving beyond the myths. *Global Environmental Change* 11, 261–269.

Leao, S., Bishop, I., & Evans, D. (2004). Simulating urban growth in a developing nation's region using a cellular automata-based model. *Journal of Urban Planning and Development 130:3,* 145–158.

le Roux, P.C., Lenoir, J., Pellissier, L. C., Wisz, M.S., & Luoto, M. (2013). Horizontal, but not vertical, biotic interactions affect fine-scale plant distribution patterns in a low-energy system. *Ecology* 94:3, 2013, pp. 671-682.

Linard, C., Tatem, A.J., & Gilbert, M. (2013). Modelling spatial patterns of urban growth in Africa. *Applied Geography* 44, 23–32.

Liu, Y. (2009). *Modelling urban development with geographical information systems and cellular automata.*188 pp. CRC Press, Boca Raton.

Luoto, M., Pöyry, J., Heikkinen, R.K., & Saarinen, K. (2005). Uncertainty of bioclimate envelope models based on the geographical distribution of species. *Global Ecology and Biogeography* 14, 575–584.

Marmion, M., Parviainen, M., Luoto, M., Heikkinen, R.K., & Thuiller, E. (2009). Evaluation of consensus methods in predictive species distribution modelling. *Diversity and Distribution* 15, 59–69.

McDonald, R.I., Green, P., Balk, D., Fekete, B.M., Revenga, C., Todd, M., & Montgomery, M. (2011) Urban growth, climate change, and freshwater availability. *Proceedings of the National Academy of Sciences* 108:51, 6312–6317.
Mundia, C.N. & Murayama, Y. (2010). Modeling Spatial Processes of Urban Growth in African Cities: A Case Study of Nairobi City. *Urban Geogprahy* 31:2, 259–272.
Myers, G. A. (1996). Democrazy and development in Zanzibar? Contradictions in land and environment planning. *Journal of Contemporary African Studies*, 14(2), 221–245.
Myers, G. A. (2002). Local communities and the new environmental planning: a case study from Zanzibar. Area, 34:2, 149–159.
Myers, G. A. (2008). Peri-urban land reform, political-economic reform and urban political ecology in Zanzibar. Urban Geography, 29:3, 264–288.
National Bureau of Statistics (NBS) (2004). *2002 Population and Housing Census: Volume IV: District Profiles*, 130 p. Dar es Salaam: Central Census Office.
NBS (2013). *2012 Population and housing census: Population distribution by administrative areas*. Dar es Salaam: Central Census Office.
Ngau, P. (2013). *For town and country: A new approach to urban planning in Kenya*. 24 p. African research institute, London.
Odendaal, N. (2012). Reality check: Planning education in the African urban century. *Cities* 29, 174–182.
Poelmans, L., & Van Rompaey, A. (2010). Complexity and performance of urban expansion models. *Computers, Environment and Urban Systems 34*, 17–27.
Revolutionary Government of Zanzibar (RGZ) (2012). *National Land Use Plan 2012*. 74 p. RGZ, Zanzibar.
RGZ (2014). *Urban Development Management Approach Report*. 285 p. RGZ, Zanzibar.
Seto, K.C.,Fragkias, M., Güneralp, B. & Reilly, M. (2011). A Meta-Analysis of Global Urban Land Expansion. *PLOS One*, 6:e23777.
Silva, A. & Wu, N. (2012), Surveying Models in Urban Land Studies. *Journal of Planning Literature* 27:2, 139–152.
Silvermann, B.W. (1986). *Density estimation for statistics and data analysis*. 22 p. Chapman and Hall, London.
Swets, K.A. (1988). Measuring accuracy of of diagnostic systems. *Science* 240, 1285–1293.
Taubenböck, H., Esch, T., Felbier, A., Wiesner, M., Roth, A., & Dech, S. (2011). Monitoring urbanization in mega cities from space. *Remote Sensing of Environment* 117:15, 162–176.
Tayyebi, A., Pjianowski, B.R. & Tayyebi, A.H. (2011). An urban growth boundary model using neural networks, GIS and radial parametrization: An application to Tehran, Iran. *Landscape and Urban Planning* 100: 1–2, 35–44.
Thomas, I.D. (1968). Geographical aspects of the Tanzania population census 1967. *East African Geographical Reviews*, 6, 1–12.
Tobler, W.R. (1970). A Computer Movie Simulating Urban Growth in the Detroit Region. *Economic Geography 46*, 234–240.
Triantakonstantis, D. & Mountrakis, G. (2012). Urban Growth Prediction: A Review of Computational Models and Human Perceptions. *Journal of Geographic Information System* 4, 555–587.
Törhönen, M. (1998). *A thousand and one nights of land tenure. The past, present and future of land tenure in Zanzibar*. 100 p. The Royal Institution of Chartered Surveyors, London.
United Nations (UN) (2004). *World Population to 2300.* 254 p. United Nations, New York.
UN (2010). *World Urbanization Prospects: The 2009 Revision.* 56 p. United Nations, New York.
UN (2014). *World Population Prospects: The 2012 Revision.* 44 p. United Nations, New York
United Nations Human Settlement Programme (UN-Habitat) (2014). *The state of African cities 2014: Re-imaging sustainable urban transition*. 278 p. UN-Habitat, Nairobi.
Vermeiren, K., Van Ropaey, A., Loopman, M., Serwajja, E. & Mukwaya, P. (2012). Urban growth of Kampala, Uganda: Pattern analysis and scenario development. *Landscape and Urban Planning* 106, 199–206.
Watson, V. (2013). African urban fantasies: dreams or nightmares. *Environment & Urbanization* 26:1, 215–231.
Von Thünen, J.H. (1826). *Der isolierte Staat in Beziehung auf Landwirthschaft und Nationalökonomie, oder Untersuchungen über den Einfluss, den die Getreidepreise, der Reichthum des Bodens und die Abgaben auf den Ackerbau ausüben*. 432 pp. Wissenschaftliche Buchgesellschaft, Darmstadt

Wood, S. (2008). Fast Stable Direct Fitting and Smoothness Selection for Generalized Additive Models. *Series B: Statistical Methodology 70:3*. 495–518.

**Supplementary materials:**

Initial independent variables were derived from six different sources (Table 1.)

*Table 1. Statistical and source information of the independent variables of the entire study area.*

| Variable | Abbreviation | Unit | Min | Max | Mean | Source |
|---|---|---|---|---|---|---|
| Distance to coast | DC | m | 20 | 8862 | 3114 | DoMS topographic database |
| Distance to markets | DM | m | 45 | 17747 | 7446 | Draft National Land Use Plan |
| Distance to roads | DR | m | 0 | 3421 | 676 | DoMS topographic database |
| Distance from buildings | DB | m | 0 | 2041 | 139 | DoMS topographic database |
| Kernel density of buildings | KER | units/km$^2$ | 0 | 2000 | 359 | DoMS topographic database |
| Focal sum of build cells | FOC | Pixels | 0 | 9 | 0.9 | DoMS topographic database |
| Elevation | ELE | m | 0 | 107 | 24 | DoMS topographic database |
| Slope | SL | degree | 0.0 | 19.8 | 1.4 | DoMS topographic database |
| Open agricultural area | OA | 0/1 | 0 | 1 | 0.07 | DoMS topographic database |
| Soil | SOIL | 0/1 | 0 | 1 | 0.19 | Hettige (1990) |
| Three-acre plots | TAP | 0/1 | 0 | 1 | 0.45 | Draft National Land Use Plan |
| Construction restriction areas | RA | 0/1 | 0 | 1 | 0.08 | Zanzibar Master Plan, DFNR and DoMS topographic database |

Multicollinearity of all independent variables was tested with Pearson's correlation coefficient (PCC) analysis (Figure 1) and Variance Inflation Factor (VIF) (Table 2), but high multicollinearity (PCC > │0.7│ or VIF > 5) was not detected.

*Figure 1. Correlation matrix of the original variables calculated with Pearson's bivariate correlation analysis.*

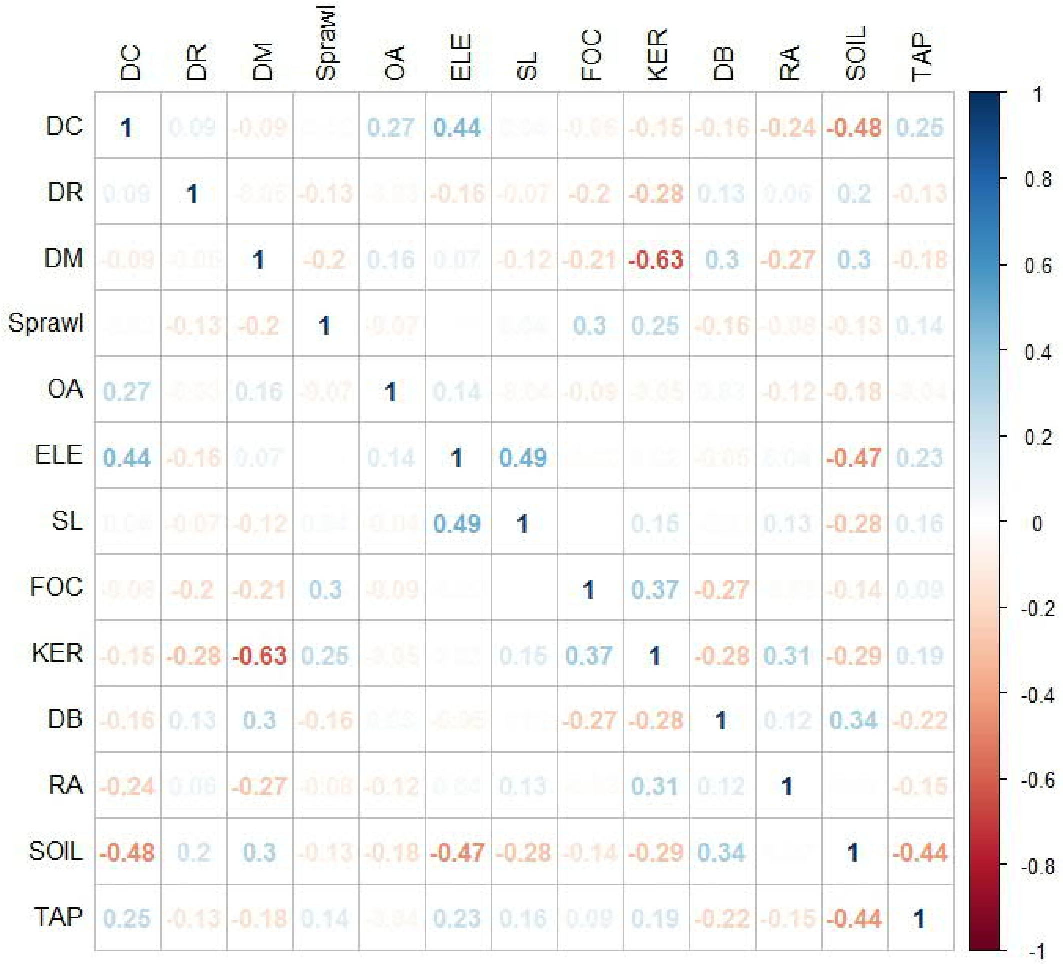

*Table 2. Variance Inflation Factor results of the remaining variables.*

| | DC | DR | DM | OA | ELE | SL | FOC | KER | DB | RA | SOIL | TAP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VIF | 2.11 | 1.31 | 2.41 | 1.21 | 2.14 | 1.49 | 1.25 | 2.61 | 1.31 | 1.40 | 2.11 | 1.34 |
| $VIF^2$ | 1.45 | 1.14 | 1.55 | 1.10 | 1.46 | 1.22 | 1.12 | 1.62 | 1.14 | 1.18 | 1.45 | 1.16 |

The variables were selected for the final model with backward stepwise selection process, where in each step the variable with biggest negative influence to the overall model was dropped (Kadane & Lazar, 2004). The negative influence was measured by variable's drop contributions TSS result (Table 3). Four steps were calculated until no more negative contributions were recorded.

*Table 3. Backward stepwise variable selection results. Grey cells indicate the variable dropped at each step and text "Dropped" indicate the variables already excluded from the model.*

| | Drop contributions | | | |
|---|---|---|---|---|
| Variable | 1st round TSS | 2nd round TSS | 3rd round TSS | 4th round TSS |
| DC | -0.0001 | -0.0006 | | |
| DR | 0.0033 | 0.0031 | 0.0041 | 0.0054 |
| DM | 0.0011 | 0.0009 | 0.0050 | 0.0064 |
| OA | 0.0004 | 0.0005 | 0.0005 | 0.0006 |
| ELE | -0.0006 | 0.0003 | 0.0016 | 0.0010 |
| SL | -0.0010 | | | |
| FOC | 0.0055 | 0.0041 | 0.0065 | 0.0062 |
| KER | 0.0140 | 0.0115 | 0.0191 | 0.0172 |
| DB | 0.0184 | 0.0157 | 0.0191 | 0.0183 |
| RA | 0.0218 | 0.0206 | 0.0277 | 0.0291 |
| SOIL | -0.0004 | 0.0001 | -0.0001 | |
| TAP | 0.0018 | 0.0018 | 0.0024 | 0.0031 |

Alternative scenarios were developed for predicting urban expansion of Zanzibar City, Tanzania (Figure 2). These scenarios were developed based on changes in patterns of urban centers, roads, construction restriction areas and airport location.

*Figure 2. Alternative scenarios of urban expansion of Zanzibar City, Tanzania. Scenario A shows the predicted expansion pattern with business-as-usual spatial pattern of growth, scenario B with eight planned new urban centers, scenario C with government areas released to infill, scenario D with new roads planned in the city region, scenario E with Abeid Amani Karume International Airport transferred away from city region and F with all these planning activities combined.*